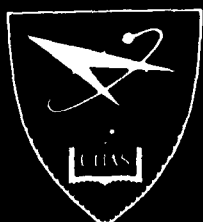


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AERODYNAMICALLY GENERATED SOUND AND SUBSONIC AERODYNAMICS

FINAL SCIENTIFIC REPORT

GRANT AF-AFOSR 75-2808

by

H.S. Ribner

January 1979

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SUMMARY

A journal version of our theory of two-point correlations of jet noise appeared during 1978: it led to an exchange of Letters to the Editor.

Jet noise diagnostics have been performed by cross-correlating the suspected source terms (e.g., rates of turbulent momentum flux) with the effect they produce. To eliminate the possibility of spurious noise, due to hot wire-flow interference, the source terms were measured with a Laser Doppler Velocimeter (after a lengthy period of development) and correlated with the far field jet noise (microphone signal). Source distribution over slices of jet inferred therefrom are, unexpectedly, somewhat pear-shaped. Spectra predicted from measured cross-spectral densities are compatible with corresponding spectra extracted from far field intensities and with theory.

Experimental studies of some unorthodox concepts for shielding jet noise have been carried out. Only modest attenuation of the peak jet noise was found with a family of half-round "sugar scoop" shields (e.g., 5-6 PNdB when scaled to a full size engine), owing largely to "edge noise" from jet interference. Another shielding concept involved extending the effective length of the "sugar scoops" by means of a hot refractive layer (array of flames). Marginal increases in shielding were found.

The UTIAS loudspeaker-driven booth was used to simulate four series of wave forms: (i) standard N-wave (ii) "quiet" boom of 2nd generation SST (iii) high pass filtered N-waves (iv) idealized quarry blast

The variation of loudness with rise time, duration and other features was assessed. Good agreement was found with an extended form of the Johnson-Robinson theory.

Our earlier work on modelling the lightning → thunder process yielded realistic computer-generated audible "thunder". Attention later shifted to modelling the tortuous lightning stroke as a random walk process. A series of assumptions on the appropriate deflection statistics eventually led to computer printouts of realistic-appearing "lightning". In recent months these 2D representations have been generalized to 3D. The lightning-thunder computer program has been correspondingly generalized; a first trial of the audible synthetic thunder has been carried out.



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INTRODUCTION

The year 1978 has seen the completion of two Ph.D. investigations: one by W.G. Richarz on jet noise diagnostics by cross-correlating laser doppler and microphone signals, and one by A. Niedzwiecki on the subjective loudness of several types of sonic boom signatures, and quarry blast waves. Additionally, the paper by the Principal Investigator detailing a theory of two-point correlations of jet noise was brought to publication, and it led to an exchange of Letters to the Editor.

The foregoing studies have generated some twelve new publications: this brings our total publications in Aeroacoustics to 107, most of them with partial AFOSR support. The cumulative publications list through no. 95 appear at the back; the new publications, nos. 96-107, are cited in the body of the report along with their abstracts. These abstracts constitute the principal content of this Final Scientific Report. (Some abstracts which are essentially included in more comprehensive abstracts are omitted).

The investigations on jet noise shielding concepts and on the lightning + thunder process have generated no publications during 1978. Progress in these areas is covered briefly in the Summary.

PUBLICATION ABSTRACTS

96. Ribner, H.S. "Two-Point Correlations of Jet Noise" J. Sound and Vibr. (1978) 56 (1), 1-19.

A large body of careful experimental measurements of two-point broad band correlations of far field jet noise has been carried out and was briefly reported recently by Lucio Maestrello in NASA TM X-72835. The rather sharp directional lobes and marked absence of axisymmetry were striking and motivated the present effort to bring theory to bear. The model of jet noise generation is an approximate version of an earlier work of Ribner, based on the foundations of Lighthill. The model incorporates isotropic turbulence superimposed on a specified mean shear flow, with assumed space-time velocity correlations, but with source convection neglected. The particular vehicle is the Proudman format, and the previous work (mean-square pressure) is extended to display the two-point space-time correlations of pressure.

The shape of polar plots of correlation is found to derive from two main factors: (1) the non-compactness of the source region, which allows differences in travel times to the two microphones - the dominant effect - and (2) the directivities of the constituent quadrupoles - a weak effect. The non-compactness effect causes the directional lobes in a polar plot to have pointed tips (cusps) and to be especially narrow in the plane of the jet axis. In these respects, and in the quantitative shapes of the normalized correlation curves, results of the theory show generally good agreement with Maestrello's experimental measurements.

97. Ribner, H.S. "Inferences of Source Coherence from Correlations of Jet Noise" Proc. 9th Internal Congress on Acoustics, Madrid, July 4-9, 1977, p.E33.

The present theory is compared with experiment (Maestrello 1976) in Figure 1. The agreement outside the "refractive zone" - not allowed for in the theory - is very satisfactory. The predicted cusps in the pattern are particularly striking.

The experimental confirmation strongly suggests the essential correctness of the source structure postulated in the theory. The sources were modelled as an array of "eddies" (correlation volumes) uncorrelated with one another and individually compact, but in aggregate noncompact.

Characterization of the source region as noncompact and essentially incoherent neither proves nor disproves a role for the large-scale coherent structures in the noise generation process. However, the experimental absence of axisymmetry in the correlation pattern rules out any significant role for axisymmetric source structures.

98. Ribner, H.S. "Author's Reply" (to Letter to Editor by Fuchs, H.V. on "Two-Point Correlations of Jet Noise and Their Interpretation, J. Sound & Vibr. (1978) 61(1), 153-156) J. Sound & Vibr. (1978) 61(1), 156-159.

No abstract. The author of Ref. 96 replies to five points raised by Dr. Fuchs.

99. Richarz, W.G. "Direct Correlation of Noise and Flow of a Jet Using Laser Doppler", UTIAS Rep. 230, AFOSR-TR-78-1648, June 1978. (Ph.D. thesis).

Lighthill's theory of jet noise, as extended and developed by Ribner (self and shear noise), has successfully described many features of the jet noise outside the 'refraction valley'. However, attempts to measure the self and shear noise source terms directly by means of a cross-correlation technique have been only partially successful. The major difficulty has been suspected as spurious 'probe noise' generated by turbulence - hot wire interaction. Thus, to avoid this problem, the traditional hot wire anemometer has been replaced in the present investigation by a non-intrusive device: a Laser Doppler Velocimeter. Substantial modifications were made to meet the constraints imposed by the correlation experiment; a major feature was provision to measure u_x , the component of turbulent velocity in the observer direction x .

Cross-correlations and cross-spectral densities of the jet noise at 40° to the jet axis and the instantaneous turbulent jet flow u_x ($\partial^2 u_x / \partial t^2$ - shear noise source term) or u_x^2 ($\partial^2 u_x^2 / \partial t^2$ - self noise source term) were measured at various source positions in the jet. Source distributions were inferred therefrom over slices of jet normal to the jet axis. They were found to be strongly pear-shaped, rather than axisymmetric, the small end of the 'pear' pointing toward the observer. (This is not, however, incompatible with the axisymmetry of far field sound intensity).

Self and shear noise spectra have been constructed from the measured cross-spectral densities by a method consistent with the postulated self/shear noise formalism. The two spectra exhibit comparable amplitudes and virtually identical shapes, but are displaced substantially in frequency: all this is predicted by the theory. Self and shear noise spectra extracted from far field jet noise intensities via an algorithm of Nossier and Ribner exhibit the same behaviour. On the whole both sets of spectra, although derived from vastly different experimental procedures, are compatible.

100. Richarz, W.G. "Direct Correlation of Noise and Flow of a Jet Using Laser Doppler", AIAA Paper 79-0571, to be presented at AIAA 5th Aeroacoustics Conference, Seattle, March 12-14, 1979. (Condensed version of Ref. 98).

Abstract condensed from that of Ref. 99.

101. Richarz, W.G. "Jet Noise Diagnostics: Spurious Sound Generated by Hot Wire-Turbulence Interaction" presented at mtg. Acoust. Soc. Amer., Honolulu, 27 Nov. - 1 Dec. 1978, J. Acoust. Soc. Amer. 64, Supp. No. 1, Fall 1978, Paper GG15.

The influence of spurious probe noise on the measurement of jet flow noise correlations has been analyzed. A simple criterion has been derived to test for the degree of "contamination" due to probe noise. It indicates that probe noise will pose serious problems in low speed jet diagnostics. Key predictions such as the shape of the expected cross-correlation function, the frequency shift of the inferred power spectral density, and the relative over-estimation of the shear noise are compatible with measurement.

102. A. Niedzwiecki and H.S. Ribner "Subjective Loudness of N-wave and Minimized ('Low Boom') Signatures, UTIAS TN 215, AFOSR-TR-78-0122 (Nov. 1977).

Abstract omitted, since this UTIAS Technical Note essentially combines the two later journal papers, Ref. 103 and 104.

103. A. Niedzwiecki and H.S. Ribner "Subjective Loudness of N-wave Sonic Booms" J. Acoust. Soc. Amer. 64(6), 1617-1621 (Dec. 1978).

A loudspeaker-driven simulation booth with extended rise time capability (down to 0.22 ms) has been used for subjective loudness tests of N-wave sonic booms. The test series compared signatures over a range of 0.22-10 ms in rise time, 100-250 ms in duration and 0.5-2.5 psf (24-120 Pa) in peak overpressure. In one sequence, the tradeoff between rise time and overpressure was measured for equal loudness; in another, the tradeoff between duration and overpressure. For equal loudness 10-ms rise time required 8-dB higher overpressure than for 1-ms rise time. Duration had little effect in the range 100-200 ms, but at 250 ms noticeably enhanced the loudness. These results confirm those measured by Shepherd and Sutherland made at 1-ms rise time and above (except for the anomalous enhancement at 250-ms duration), and extend the measurements down to 0.22 ms. There is also good agreement with theoretical predictions (Johnson-Robinson, Zepler-Harel methods) except for the 10-ms rise time and 250-ms duration cases.

104. A. Niedzwiecki and H.S. Ribner "Subjective Loudness of Minimized Sonic Boom Waveforms" J. Acoust. Soc. Amer. 64(6), 1622-1626 (Dec. 1978).

For very long supersonic aircraft the "midfield" sonic boom signature may not have evolved fully into an N-wave at ground level. Thus in current boom minimization techniques the shape of the aircraft may be tailored to optimize this midfield wave form for reduced subjective loudness. The present investigation tests a family of "flat-top" waveforms cited by Darden: all but one have a front shock height (Δp_{SH}) less than the peak amplitude (Δp_{MAX}). For equal subjective loudness, "flat-top" vs N-wave (peak overpressure Δp_N), the peak amplitude of the "flat-top" signature was found to be substantially higher than that of the N-wave; thus for equal peak amplitude the "flat-top" signature was quieter. The results for equal loudness were well fitted by an empirical law $\Delta p_{SH} + 0.11 \Delta p_{MAX} = \Delta p_N$; the equivalence shows how the front shock (Δp_{SH}) dominates the loudness. All this was found compatible with predictions by the method of Johnson and Robinson.

105. A. Niedzwiecki "On the Loudness of Sonic Booms and Other Impulsive Sounds", UTIAS Rep. 236, AFOSR TR No.(pending), Dec. 1978 (Ph.D. thesis).

A loudspeaker-driven simulation booth with extended rise time capability (down to 0.22 ms) has been used for subjective loudness tests of sonic boom and other types of impulsive sounds. The first series compared N-waves over a range of 0.22 to 10 ms rise time, 100 to 250 ms duration and from 0.5 to 4 psf (the latter for the longer rise times) (24 to 192 N/m²) peak overpressure. The response tradeoff between rise time and overpressure, and duration and overpressure was measured. For equal judged loudness, 10 ms rise time required 8 dB higher overpressure than for 1 ms. Duration had little effect in the range 100 to 200 ms but at 250 ms noticeably enhanced the loudness. These results confirm those measured by Shepherd and Sutherland (except for the 250 ms duration), and extend the measurements down to 0.22 ms rise time.

The second series tested certain "flat-top" sonic boom signatures, which according to current theory could be generated by special very long SST aircraft designed for minimized sonic boom; these were compared for loudness with a reference N-wave ($p_N = 0.5$ psf, 1 ms rise time, 150 ms duration). The subjective loudness was found to be dominated by the front (or rear) shock Δp_{SH} while the maximum peak amplitude Δp_{MAX} of the inclined "flat-top" had only a small effect. The results for equal loudness were well fitted by an empirical law $\Delta p_{SH} + 0.11 \Delta p_{MAX} = \Delta p_N$. This shows that for equal loudness the peak amplitude Δp_{MAX} of the flat-top signature is substantially higher than that of the N-wave; thus for equal amplitude the flat-top signature is the quieter.

The third series compared filtered N-wave signatures, using a high-pass digital filter, with an unfiltered N-wave signature (1 psf, 1 ms rise time, 150 ms duration). Two cut-off frequencies were used: 25 and 50 Hz. The amplitude differences for equal loudness were very slight: less than 0.6 dB at most. Thus the 'infrasonic' low frequency content of sonic boom N-waves - although it dominates the spectrum - has no significant influence on the

subjective loudness. Similar tests with annoyance as a judgement criterion has showed a tendency to increase annoyance for filtered N-waves, but again this was very slight.

In the last test series the trade-off between overpressure and duration was found for idealized quarry blast signatures composed of sequences of 25 ms long pulses with 0.22 ms rise time. The range of durations extended from 25 to 400 ms. At the short durations the loudness increased 2 dB for each doubling of duration; above 100 ms the increase was progressively lower, approaching as an asymptote the level of continuous sound.

The results in each series were compared with theoretical predictions by the method of Johnson and Robinson. All but the long duration quarry blast judgements were found to be in very good agreement in terms of relative loudness levels. With an ad hoc - but physically plausible - modification (including adjustment of the critical integration time of the ear) the predictive method was extended to encompass the long duration signals as well. Thus the applicability of the method has been demonstrated for other types of transient sounds than the N-wave; and the extension to the method appears to bridge the range between impulsive and continuous sounds of similar spectral content.

106. A. Niedzwiecki and H.S. Ribner "Subjective Loudness and Annoyance of Filtered N-wave Signatures" J. Acoust. Soc. Amer. (in press).

Abstract is essentially that for the "third series" of tests discussed under Ref. 105.

107. A. Niedzwiecki and H.S. Ribner "Subjective Loudness of Simulated Blast Waves, with Implications for the Transition from Impulsive to Continuous Sound" J. Acoust. Soc. Amer. (in press).

Abstract is essentially that for the "fourth series" of tests discussed under Ref. 105.

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